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Quality of marine observations

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The use of output from a numerical model to monitor the quality of marine surface observations

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Summary

To make optimum use of meteorological observations it is essential that regular monitoring is performed to identify those of poor quality. Output from numerical forecast models has proved to be very valuable for this purpose; short-period forecasts or background fields provide accurate global reference values against which observations may be compared. This paper presents some recent results of the monitoring of wind and pressure observations from ships and buoys using output from the UK operational global model.

1. Introduction

Great advances have been made in numerical modelling over the past two decades, and today we take for granted levels of accuracy in the forecasts of the basic meteorological parameters of mean-sea-level pressure, temperature and wind which were seldom achieved in the past. Central to the success of numerical weather prediction is the process of data assimilation by which the initial analyses or start fields are created. The methods of data assimilation ensure that the initial analysis, from which the numerical forecast is made, includes the information contained in meteorological observations, not just at one data time, but over perhaps a few days. Data assimilation is performed in a cyclical fashion — observations valid around a given analysis time are checked for quality before being merged with values from the numerical model to provide the starting analyses. A short-period forecast (usually 6 hours) is made from the analysis to create the starting point for the assimilation cycle at the next analysis time. The data assimilation method used in the UK operational models is described by Atkins and Woodage (1985), and details of more recent modifications are contained in Lorenc *et al.* (1991). Global analyses from such numerical systems achieve a realistic fit to all the data available,

and moreover they inherit a realistic three-dimensional meteorological structure from the numerical model. As a consequence they show a high degree of accuracy, as do the short-term forecasts or background fields.

The success of numerical weather prediction depends critically on the quality of the observations used in the data assimilation. Quality-control checks are essential to weed out those observations too much in error to be of value, and many algorithms have been developed for this purpose — checks may be performed to identify incorrect message format, excess over climatological extremes, internal inconsistency, and inconsistency with neighbouring observations. Fields from a numerical system have a valuable role in quality control; they provide reliable reference values against which observations separated in space and time may be checked. Observation errors can be identified as long as they are not much smaller than the expected error of the field. However, the method has its limitations. Firstly, numerical models can at best only represent values on the coarse scale of their grid and will not be able to resolve much of the observed fine-scale structure of the atmosphere. Secondly, model fields are most accurate where there is a good coverage of observations and in

data-sparse areas they may contain substantial systematic and random errors.

At any one datum time two types of model field are available for assessing observation quality — an analysis and a background. The analysis represents the best fit to all observations passing the quality checks which are available up to that given time, and the background represents the best estimate of the observed values at the current time using only information contained in observations valid at earlier times. Because background values are generally independent of the current observations, they are found to be most suitable for studies of observation quality. Observation-minus-background differences (from now on referred to as O—B) are at the centre of many studies of data quality. Errors in both observations and background will contribute to the value of O—B, and the success of data monitoring depends on identifying those cases where the magnitude of O—B is too large to be due to background error alone.

Background values may be used in two quite different ways. Firstly, as part of an assessment of the quality of a set of observations valid at just one time. Such checks, often performed in real time, may be used as mentioned above to weed out those observations too erroneous for use in numerical data assimilation. The use of background values for this type of quality control, as it is performed for the operational forecasting models at Bracknell, is described by Bell and Dickinson (1987) and a description of more recent developments is contained in Lorenc and Hammon (1988). Secondly, they may be used to assess the quality of a sequence of observations from one source over a long period of time. For example, values of O—B for pressure observations from a ship with a given call-sign may be monitored over a period of a month or more to identify systematic departures from background values. In such a case the bias and standard deviation of O—B prove to be very valuable indicators of observation quality. This paper is concerned principally with the second monitoring method using period averages. The basic assumption lying behind this method is that the magnitude of the background errors, both systematic and random, averaged over a period of a month or more, varies only slowly in space. The assumption is generally valid in the free atmosphere and close to a homogeneous surface such as the open sea. On any one occasion, background errors may vary greatly within a small region, but the average over a month or more is found to vary little. In contrast, average observation errors may differ greatly between neighbouring stations or between national groupings of stations operating different types of instrument. Differences from background which are larger than the local average can therefore, in most cases, be attributed to larger than normal observation errors.

This paper describes some monitoring methods applied to surface observations of pressure and wind

from marine sources — that is from ships, drifting buoys, and fixed buoys and platforms. Model fields are particularly suitable for the monitoring of observations of this type; they are at one level, and in the case of pressure relate to one of the basic model parameters. Moreover, the sea surface is relatively uniform and meteorological structure is less complex than over land where there is more fine-scale detail. Errors in marine observations may arise from a number of sources; the instrument may be malfunctioning or miscalibrated, figures may be mistaken while being transferred manually, or there may be corruption of data during transmission. A poorly sited anemometer can result in errors in the observations of wind. Errors can also arise in the pressure report if the adjustment to sea level is made incorrectly or not at all. In the case of a large ship, failure to allow for the changes in the barometer height due to changes in the ship's draught can lead to an error of perhaps 1 mb or greater. Some of these errors can be detected in real time by applying checks on the code format and the internal consistency of the report, but most information on quality can only be obtained by studying long sequences of observations from one ship or buoy.

Taking all marine surface observations together, the values of O—B have distinct characteristics. The vast majority of the observations show quite small departures from background and the distribution of O—B is nearly Gaussian with little or no bias. The errors in the background field probably contribute most to the values of O—B for these observations. There is, however, always a smaller group of observations departing much more from background for which observation error is the only reasonable explanation for the large values of O—B. Studies of the distribution of O—B and its variation at different points around the globe enable reasonably accurate estimates of background error to be made, and this provides the basis for the monitoring methods described here. Those ships or buoys for which, in a sufficiently large sample, the observed values of pressure or wind differ from the background by an amount greatly in excess of the estimate of background error, may be labelled as suspect with a high degree of confidence.

Recognizing the value of numerical fields for monitoring purposes, the WMO Commission for Basic Systems agreed in 1985 that there was a need for global NWP centres to co-ordinate their activities and ensure that feedback was provided to those responsible for making the observations. Since then a regular exchange of monitoring results has been established between a few active centres — the Meteorological Office, ECMWF, NMC Washington, and Tokyo. In 1988, three lead centres were nominated by WMO to produce lists of suspect stations at 6-monthly intervals for given data types, together with information on the nature of the error. Bracknell was allocated the role as lead centre for marine surface observations, ECMWF for radiosondes,

and Washington for satellite and aircraft data. Some of the monitoring work performed at ECMWF, mainly relating to radiosonde observations, has been described by Radford (1987). This paper covers some of the activities at the Meteorological Office, Bracknell in its role as a lead centre.

2. Monitoring results

2.1 Pressure

In a typical month about 110 000 surface reports from ships and buoys are received at Bracknell in time for use in the numerical forecasting system. The number of reports received from any one ship is very variable; there can be long gaps while it is in port or out of service, and while at sea some report rather infrequently. In any month about 4000 different ships each provide more than 20 reports, which is around the minimum number required for monitoring purposes. There are also about 170 moored buoys and platforms and 200 drifting buoys each providing at least 20 reports per month.

A histogram of O—B differences for all ship pressure observations in the period January–June 1990 is shown in Fig. 1(a), together with the Gaussian distribution with the same mean and standard deviation. Although almost all values fall within the range +5 to −5 mb, a small number of very large values, presumably resulting from erroneous observations, contribute to the large standard deviation of the population. Some of the largest differences from background are often due to coding errors in the 10 or 100s units and are easily detected by the automatic quality-control checks. The distribution of all those observations which fail these checks, and are therefore not used in the data assimilation, is broad and bimodal (Fig. 1(b)). The remaining 92% of the observations which pass the quality checks show a distribution of O—B which is very close to Gaussian (Fig. 1(c)); it has a mean of 0.0 mb and a standard deviation of 1.6 mb, and the principal contribution to the variance is assumed to be from background errors.

A global estimate of the background error, such as is provided in Fig. 1(c), will conceal large variations which may occur from place to place. Background values are likely to be most accurate in data-rich areas, such as in the North Sea or Mediterranean, or in areas such as the tropics where meteorological variability is low. In order to investigate the geographical distribution, values of O—B from observations which pass the quality-control checks have been calculated for 10° latitude–longitude boxes. The mean and standard deviation of O—B are plotted in Fig. 2 provided there are at least 10 observations available within a box. Observations of pressure from ships at all synoptic hours have been used over the 6-month period January–June 1990, and the number of reports in each 10° box, on which the calculations are based, is shown in Fig. 3. In almost all
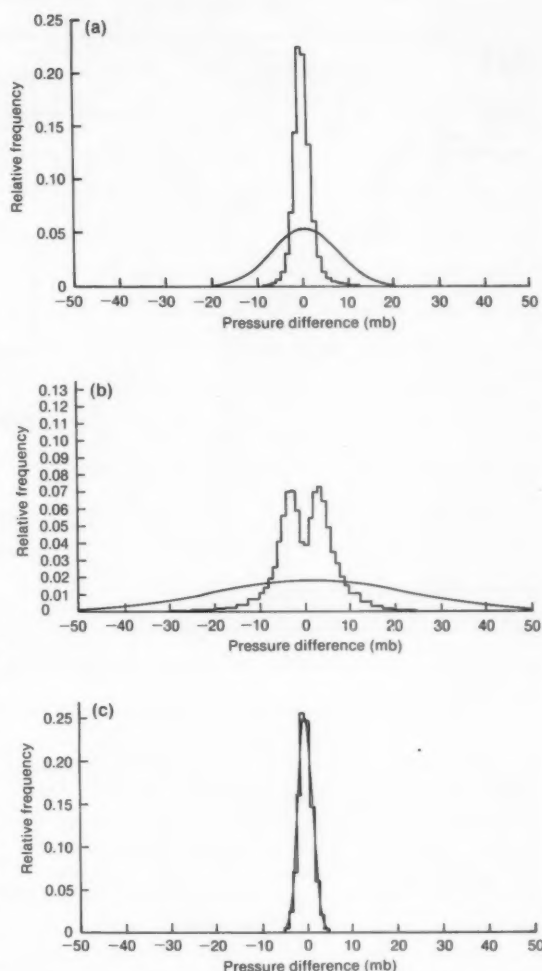

Figure 1. Histograms showing the distribution of O—B for pressure observations from ships for the period January–June 1990 for (a) all observations, (b) only observations failing quality checks, and (c) only observations passing quality checks. Gaussian distributions with the same mean and standard deviation are also plotted.

areas the magnitude of the mean is less than 1.0 mb, the exceptions being in the high latitudes of the southern hemisphere where only a small number of observations are available. In some boxes the statistics may be dependent on just one or two ships which have passed through the area in the period. Clearly a systematic bias in the observations from one of them will show a strong signal in the values shown; it is only in the data-rich regions of the main shipping lanes that there are enough observations from independent sources to smooth out such irregularities. The average standard deviation shows a great deal of variability with location; in the tropics the value lies between 1.0 and 1.5 mb, in northern latitudes between 1.5 and 2.0 mb, and in the Southern Ocean between 2.0 and 3.0 mb. The higher values reflect the effect of greater meteorological
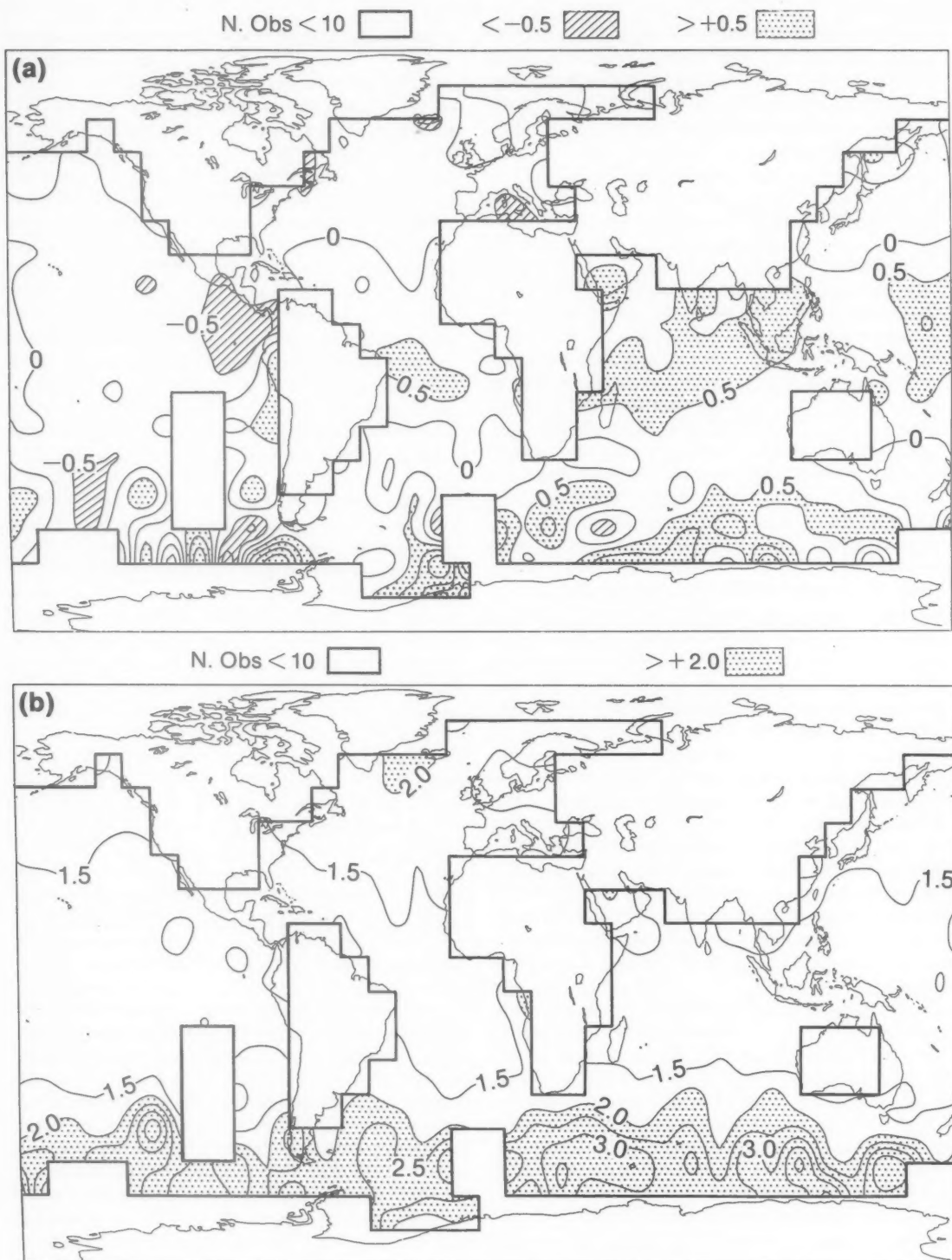
Figure 2. Average over the 6-month period January–June 1990 for (a) the mean, and (b) the standard deviation of O−B for pressure observations from ships which pass the quality-control checks. The contoured values are based on averages for 10° boxes where more than ten reports were available.
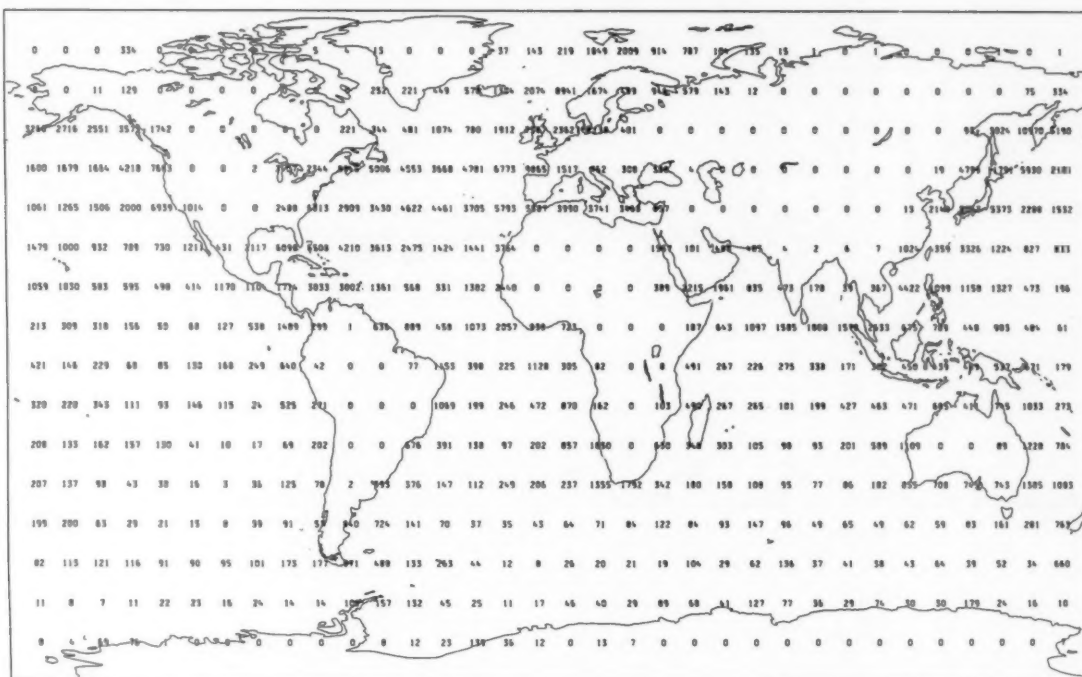
Figure 3. The number of ships within each 10° box in the period January–June 1990 used in Fig. 2.

variability and the higher background errors in areas where there are few observations.

The best way to display monitoring results for a given ship or buoy is in the form of a time sequence of values of O−B as in Fig. 4. The crosses represent the difference from background for each pressure observation from a ship operating in the North Sea and reporting regularly at each of the four main synoptic hours 00, 06, 12 and 18 UTC. The period covered is January–June 1990. The mean of the sample is +0.4 mb and the standard deviation 1.1 mb, which are close to the average for all reports from that area. The departures from background appear largely uncorrelated from one observation time to the next and can be attributed to random errors in the background values. It is noticeable that the scatter is larger in the first three months than it is in the last three, and this is almost certainly due to seasonal variability in the background errors; model forecast errors are larger in the winter than in the summer. There are four observations which differ substantially more from the background than the rest of the population: one value of O−B falls outside the plotting limits of the figure, and the magnitude of the others is close to 10 mb. The differences in the last three cases is no doubt due to an error of 10 being made while taking the pressure reading or while the figures were transcribed. This example is typical in that, for the great majority of ships, the values of O−B for pressure show a similar scatter about the zero axis, though few report quite as frequently.

Fig. 5 displays values of O−B for a ship on routes between Europe and the Caribbean, and the periods of 3 weeks or so spent in port account for the regular gaps in the sequence. In this case the observations of pressure show a bias with respect to background which remains at around +7 mb throughout the entire period. The standard deviation of the sample is 1.8 mb which is not much larger than average for the region in which the ship is operating. One likely reason for the errors is a miscalibration of the instrument. There are, however, two values of between +15 and +20 mb, deviating significantly from the rest of the sample, which seem to be in error for other reasons. Perhaps again a coding error of 10 mb has been made on these occasions. Instances of a bias in the observations of pressure from ships, which remains constant over long periods of time, are surprisingly common; regular monitoring at Bracknell shows that about 150 ships may be identified at any one time with a constant bias in excess of 2 mb in magnitude. In most cases, as in this example, the standard deviation is small. Where the bias is relatively small the cause of the error may be a failure to make a proper correction to sea level. On a large ship, the barometer may be at a height of perhaps 30 m, and the adjustment to give the value of pressure at mean sea level is about 3 mb depending on the temperature. Where the adjustment is made incorrectly, or not at all, an error will arise. A particular problem occurs where the height of the barometer changes due to changes in the draught of the ship; there will be errors of up to 1 mb or greater if this is not taken into account.
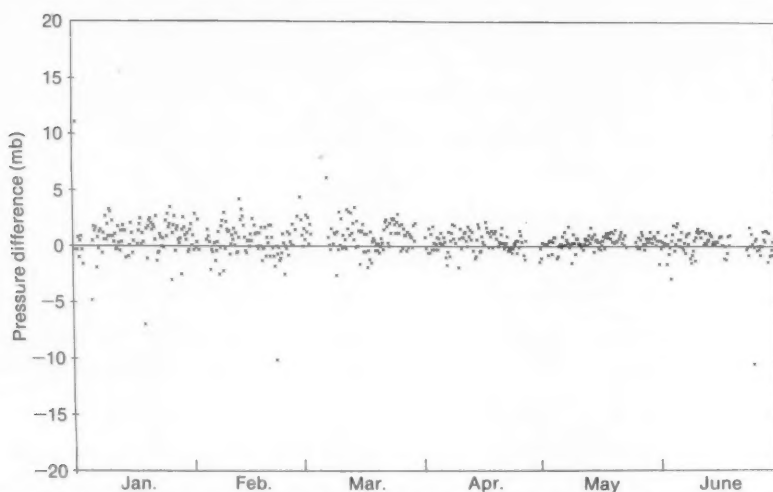
Figure 4. A time series of O−B for pressure observations from a ship in the North Sea for the period January−June 1990.
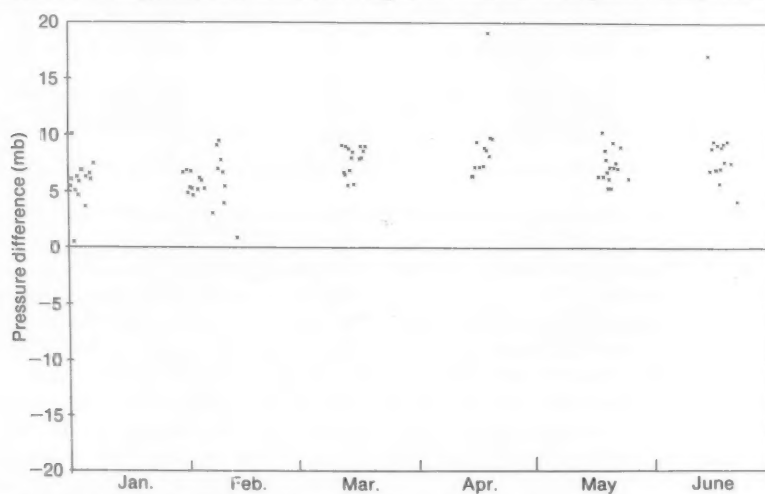

Figure 5. As for Fig. 4, but for a ship on routes between Europe and the Caribbean.
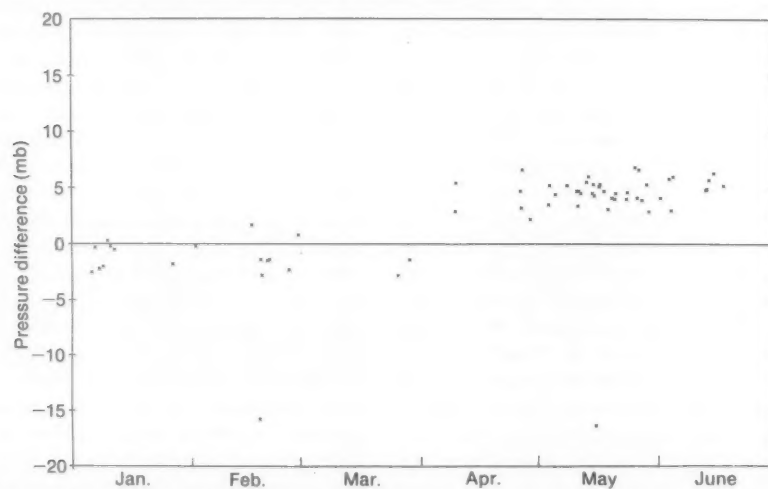

Figure 6. As for Fig. 4, but for a ship in the Mediterranean and Black Sea.
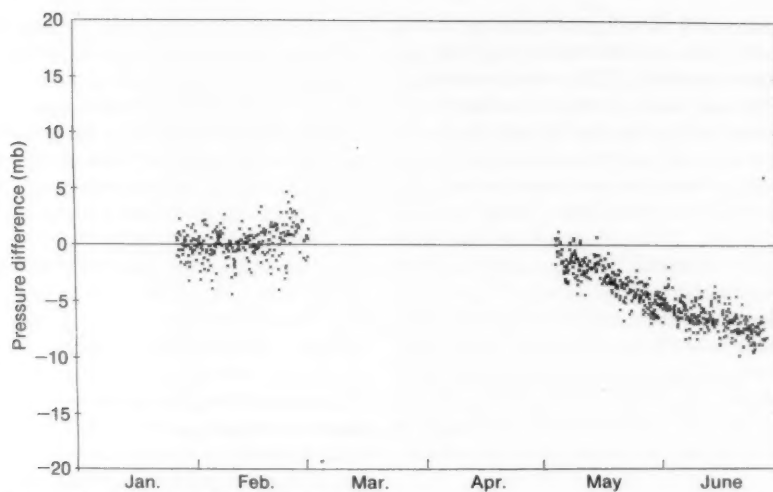
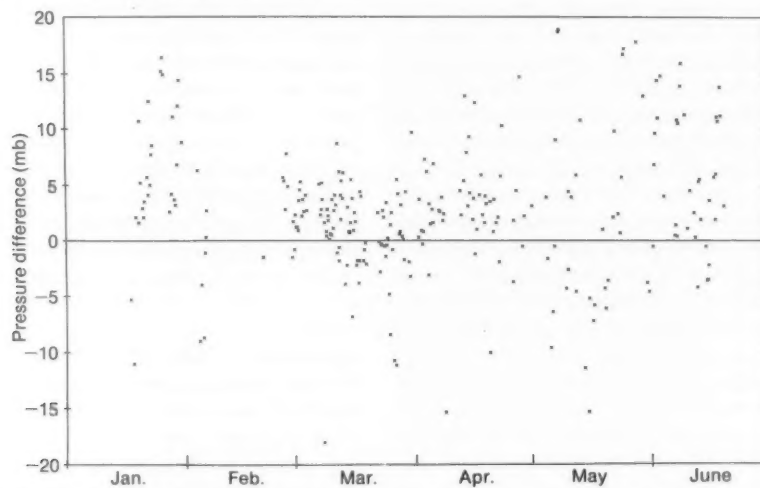**Figure 7.** As for Fig. 4, but for a buoy in the Gulf of Mexico.

Figure 8. As for Fig. 4, but for a ship in the Southern Ocean.
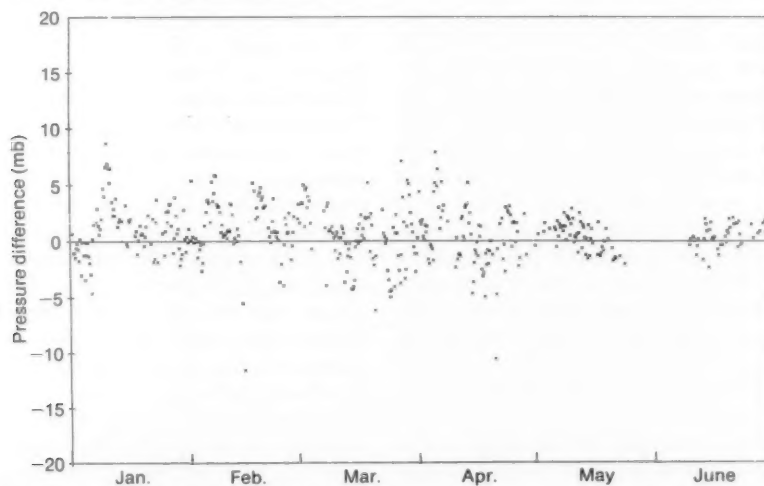

Figure 9. As for Fig. 4, but for a second ship in the Southern Ocean.

Time sequences of O−B will enable changes in the observation quality to be easily identified. Fig. 6 shows a case of a ship, operating in the Mediterranean and Black Sea, where a pressure bias developed suddenly; the observations seemed of good quality up to the beginning of April, but after that date all showed a bias of +5 mb. Again, two extreme values are evident where presumably there is a separate cause of the error. Most biases in pressure observations from ships seem to occur suddenly, as in this example, pointing perhaps to an occasion when the instrument became maladjusted or damaged, or the observation practice changed. In a few instances, particularly with the automatic instruments on a buoy, the bias grows gradually over a long period of time as the example in Fig. 7 shows. This drifting buoy is in the Gulf of Mexico and the bias increases in magnitude from near zero to −8 mb over a period of 2 months.

In all of the examples shown so far the errors have been systematic in that the standard deviation of O−B has been small at any one time. In a few cases the occurrence of large random errors may be very frequent as the example in Fig. 8 demonstrates; 65 of the 338 reports fall outside the plotting limits of this diagram, and those of magnitude less than 15 mb have a standard deviation of 5.0 mb. Occasionally the position of the ship in question appeared to be miscoded with east reported instead of west, or north instead of south, but this was not the major source of error. Over the 6 months it covered a wide area in the Southern Ocean off the Antarctic continent with excursions to New Zealand and South America. Model errors are known to be largest in these regions, and it is important to take into account the location of the ship before deciding what part of O−B may be attributed to observation error and what to background error. Fig. 2(b) shows that the standard deviation of O−B in the Southern Ocean is on average some 2 to 3 times larger than in the tropics, but it is nevertheless much less than found in this example. It certainly seems that the observations are highly unreliable, and this is confirmed by comparison with the time sequence of O−B pressure values shown in Fig. 9. In this case the observations came from a research ship which during January−March was at similar high latitudes of the southern hemisphere. The scatter of O−B is clearly much smaller and the standard deviation of 2.7 mb is very close to the average value for the region. From mid April to mid May the ship steered north across the tropical Atlantic to Europe and, after a spell in port, left for Arctic waters in June. The standard deviation of O−B in this second period is noticeably lower than in the first 3 months. It can be seen that the standard deviation of O−B for each part of the route taken by a ship is close to the average values shown in Fig. 2(b).

The mean (M) and standard deviation (S) of the differences from background are clearly very informative measures of observation quality:

$$M = \overline{(o-b)}, \quad S = \{\overline{(o-b)^2} - M^2\}^{\frac{1}{2}}$$

where o is the observed value; b the background value; and the mean, indicated by the overbar, is taken over a period of a month or more. However, as the last example shows, background errors may vary a great deal across the globe and ideally this should be taken into consideration as well. If t is the true value at the observation position, the true observation bias (TB) is given by

$$TB = \overline{(o-t)} = \overline{(o-b)} - \overline{(t-b)}.$$

Use can be made of the global statistics for each 10° box shown in Fig. 2: assume that the ship in question remains in one box where the mean O−B for all ships' observations passing the quality-control checks over a long period of time is m and the standard deviation s. In a large sample the mean observed value can be expected to be close to the mean of the true value, so a good approximation to $\overline{(t-b)}$ is m, and

$$TB = \overline{(o-b)} - m.$$

This represents quite a small correction to the estimate given by M as the local average m seldom exceeds 0.5 mb in magnitude. A normalized standard deviation NS may be defined by

$$NS = \{\overline{((o-b-m)^2 - TB^2)/s^2}\}^{\frac{1}{2}}$$

which takes a value of 1 if the standard deviation of O−B for the ship in question is equal to the past average for all the other ships in the box, and a value of 2 if it is twice as large, and so on. TB and NS have been calculated assuming that the ship remains in the same area so that m and s are fixed, but they can equally well be calculated allowing m and s to vary as the ship moves from one part of the globe to the other. Values of TB and NS calculated in this way are routinely monitored at Bracknell for all ships reporting regularly on the Global Telecommunication System (GTS).

Monitoring statistics are supplied each month to those responsible for the quality of observations exchanged on the GTS. The Marine Division at Bracknell is one such group receiving lists of ships for which the mean and standard deviation of O−B is much larger than average. They scan the lists for ships in the UK Voluntary Observing Fleet (VOF), and where a suspect case is found, the Port Met. Office network is alerted and a visit is made to the ship at the earliest opportunity. A recent example of the procedures in action concerns a support vessel, newly recruited to the UK VOF, stationed in the North Sea. Values of the standard deviation of O−B had been found to be very large and the Port Met. Officer visited the vessel to ensure that the observing staff understood how to read

the barometer and that the right corrections were being applied. However, the fault was finally found to be in the reporting of longitude which was coded as 20° E instead of 2° E. A time series of O—B pressure is shown in Fig. 10 for the relevant period. A sudden improvement in October 1990 followed the visit, marred only by a brief reversion to the erroneous practice for a week in December.

2.2 Wind

Observations of wind from ships and buoys can be monitored in a similar way to the observations of pressure. On the majority of ships, wind is measured using anemometers which may be fixed or hand-held. The reported speed will be dependent on the period over which the readings have been averaged, and the height of the instrument above mean sea level, both of which will vary a great deal from ship to ship. The wind flow is distorted by the structure of the ship, and factors affecting the wind measurement will include the siting of the anemometer, the size of the ship, and the bearing of the wind with respect to the alignment of the ship. It is common for the measurement to be taken visually from a dial, and a tendency to report gust values rather than time averages will lead to overestimation of the speed. Another cause of error in ship observations of wind may be a failure correctly to allow for the motion of the ship. The wind reports from other ships, such as those of the UK VOF, are based on visual estimates of the sea state and in these cases the factors outlined above do not apply.

For the monitoring results presented here the values of the background wind at the lowest model level (approximately at 25 m) have been used. Where ship winds are measured by an anemometer an apparent speed bias will be introduced into the values of O—B if its height is greatly different from 25 m. Another source of error is of course a systematic bias in the background values which is difficult to estimate independently of ship observations.

Histograms of O—B differences of wind speed are presented in Figs 11(a)—11(c) in the same way as in Figs 1(a)—1(c). As with observations of pressure, those wind observations which fail the quality-control checks show large differences from background, some in excess of 50 m s^{-1}, and as a result the standard deviation is large. The distribution of O—B wind speed for the remaining 96% of the observations is nearly Gaussian with a bias of +1.2 m s^{-1} relative to background and standard deviation of 3.3 m s^{-1}. The bias is about 15% of the mean observed speed. The difference between the height of the anemometer, where one is used for wind measurement, and the height at which the background is valid (25 m) has already been mentioned as a source of bias in O—B, but it alone seems unlikely to account for the magnitude of the bias found here. Rahmstorf (1989) demonstrated that routine wind reports prepared by ships' officers from reading the mast anemometer were higher than those measured by an anemometer sited on a long boom suspended from the side of the ship to minimize the effect of the ship superstructure. He found differences as large as 30% in moderate to strong winds.
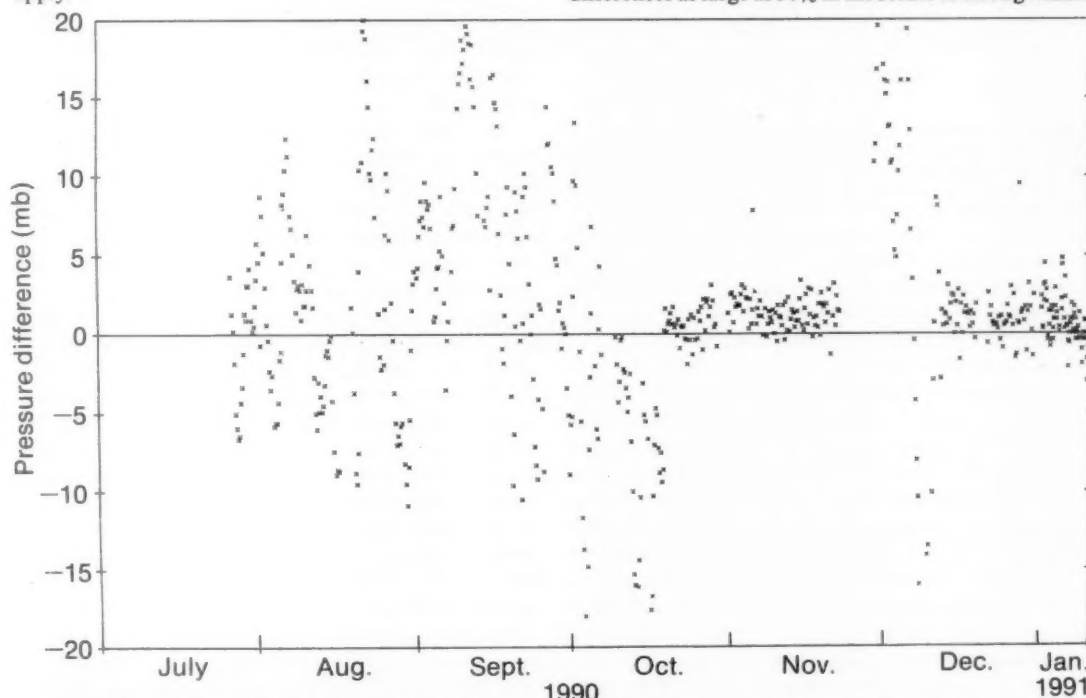

Figure 10. As for Fig. 4, but for a ship of the UK VOF in the North Sea for the period July 1990—January 1991.
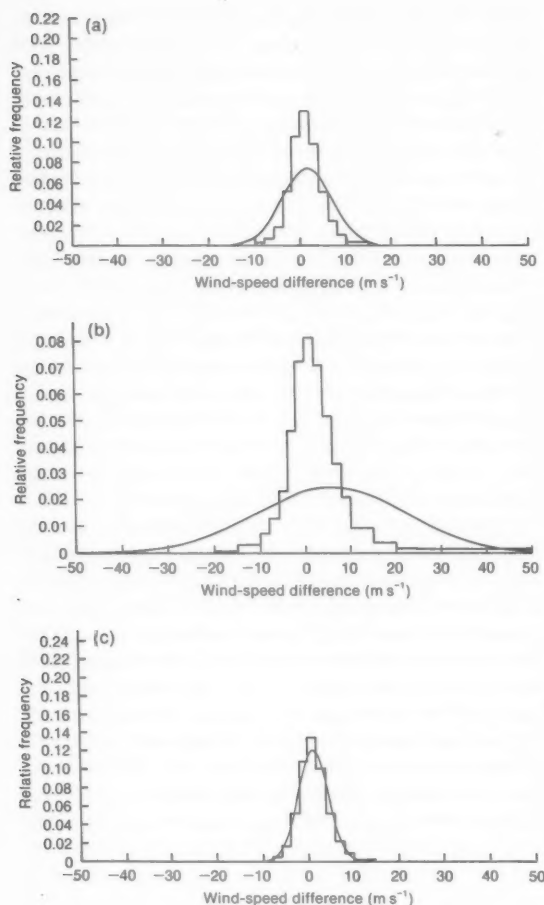
Figure 11. Histograms showing the distribution O−B for wind speed observations from ships for the period January−June 1990 for (a) all observations, (b) only observations failing quality checks, and (c) only observations passing quality checks. Gaussian distributions with the same mean and standard deviation are also plotted.

Other studies (e.g. Wilkerson (1986)), where comparisons have been made with observations from moored buoys, also show a positive speed bias in ship winds, and indicate that many are of suspect quality.

Ocean Weather Ship *Cumulus*, operating to the west or south-west of Britain at around longitude 20° W, provides a useful source of wind observations for reference. The ship is small and wind is measured by two anemometers, one on each side of the aft mast, at a height of 23 m above the sea surface. Values of O−B for the speed and direction over the period January−June 1990 are plotted in Figs 12(a) and 12(b). Values of direction have not been plotted if the speed is less than 5 m s^{-1}. The mean speed bias of −0.1 m s^{-1} is very small compared with the positive bias found from all ship observations taken together. Although not evident here because of the lack of reports, values of O−B for wind from many ships and buoys are smaller in the summer

months, as they were for observations of pressure, reflecting the lower background errors.

Some ships show a speed bias considerably larger than average as Fig. 13 shows. In this case the ship was on routes in the Atlantic, Pacific and Indian Oceans during the 6-month period. After providing seemingly reliable observations for the first 4 months a bias of +10 m s^{-1} developed in May. In a similar way systematic differences between the observed and background wind directions are easily identified by inspection of a time series. Such problems can be found in observations from buoys and other automatic stations, and may be confidently attributed to observation error where they occur over the open ocean. Care must be taken if the observing position is close to the coast; the background values may be derived from land points in the model, and systematic errors of the numerical forecasts may be much larger than average, particularly if the land rises steeply to some coastal mountain peaks. An example of a direction error is shown in Fig. 14. The buoy in question is in the Arctic Ocean far from any land, and a constant bias of 130° is evident in the reported direction.

3. Concluding remarks

The examples presented above demonstrate the value of fields from a numerical forecasting system in the monitoring of the quality of meteorological observations. The numerical fields are particularly suitable as reference values; they are global in extent and are consistent both in space and time. On most occasions their accuracy is such that quite small observation errors may be detected. It is essential in all cases that the likely magnitude of the background error is quantified, and this is best done by reference to observations of known high quality.

The most important result obtained from the monitoring work performed at Bracknell is the identification of a large number of ships for which the observations of pressure appear to be of poor quality. In many cases there is a bias which remains constant for many months or even years; at any one time around 150 ships fall into this category. Apart from the bias, the observations from these ships appear to be of good quality. In addition there are in excess of 50 other ships where there are regular large errors in the pressure observations of a more random nature. The monitoring of observations of wind from ships shows that the reported speed is on average positively biased with respect to the background. The wind speed observed at weather ships, where the observing practices are known to be reliable, shows no such bias. Unlike the case of pressure, there are few ships reporting wind which stand out far enough from the average to be confidently labelled as suspect.

Monitoring serves no useful purpose unless it leads to improvements in the observing system. Recognizing this, WMO established lead centres for the monitoring of different types of observations, and since 1987
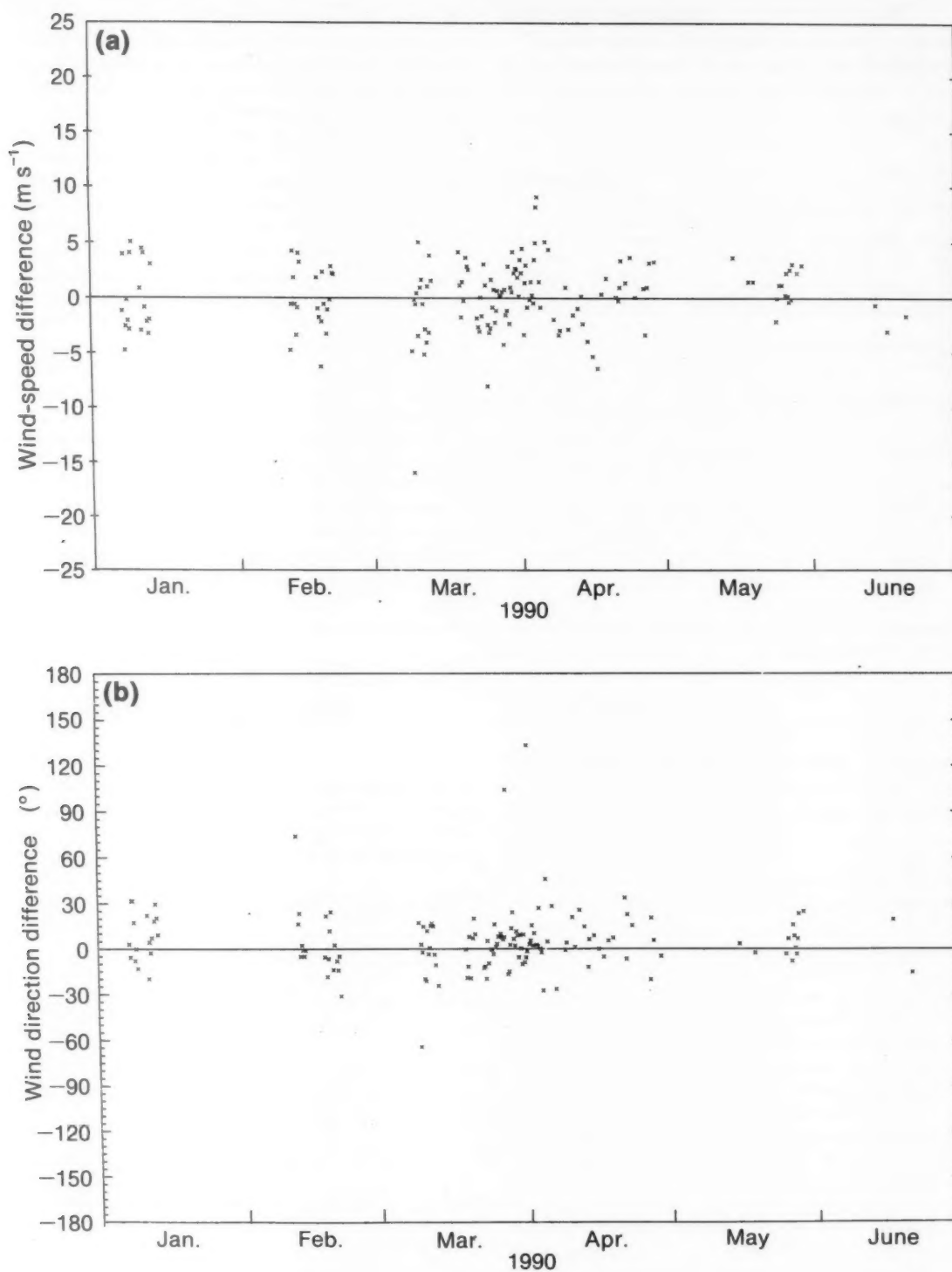
Figure 12. A time series of O−B for (a) wind speed, and (b) wind direction observations from Ocean Weather Ship *Cumulus* for the period January–June 1990.
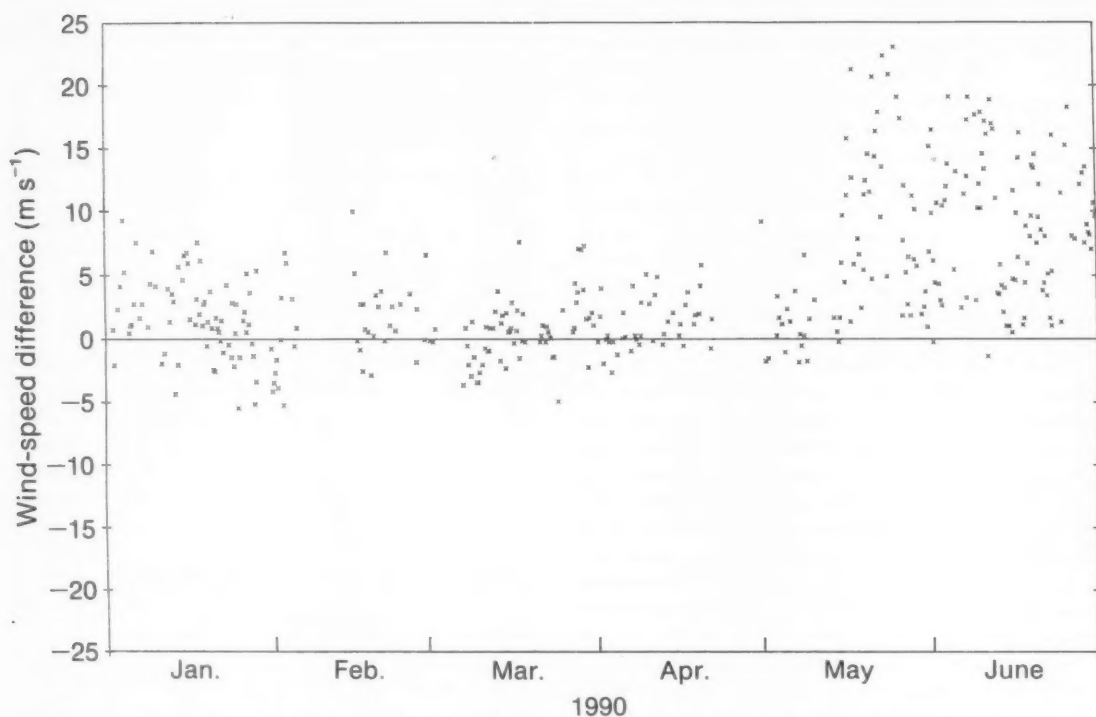
Figure 13. A time series of O—B wind speed observations from a ship on routes in the Atlantic, Pacific and Indian Oceans for the period January–June 1990.
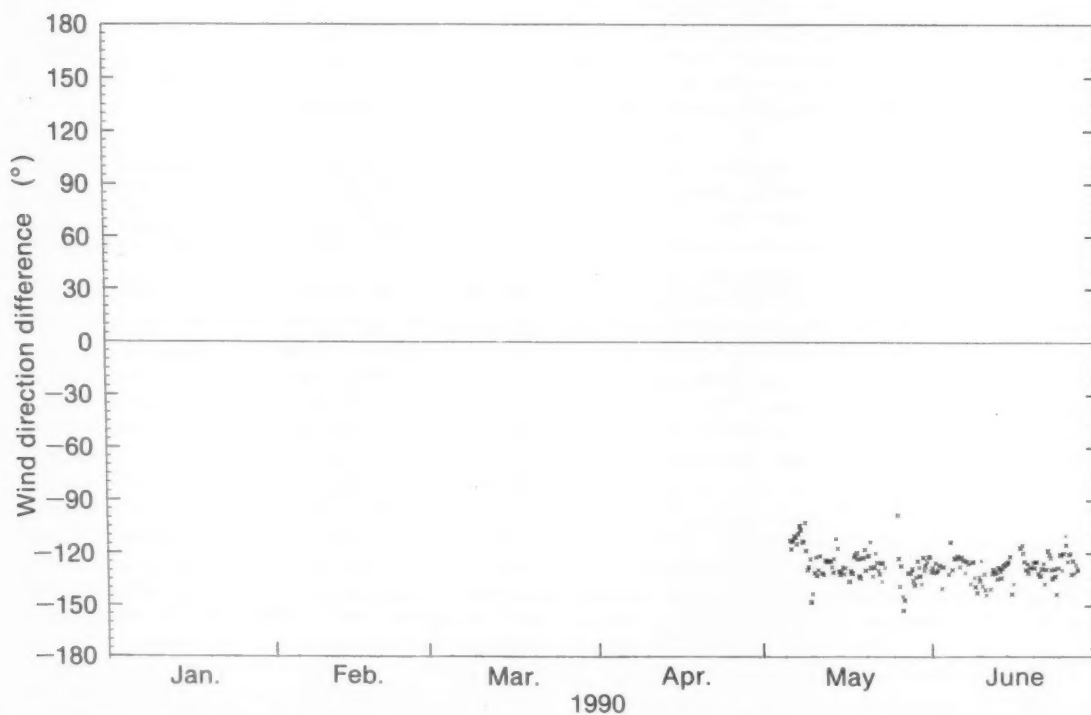

Figure 14. A time series of O—B wind direction observations from a buoy in the Arctic Ocean for the period January–June 1990.

Bracknell has been fulfilling its role as lead centre for marine surface data. Monthly monitoring statistics are routinely provided to some of the centres operating VOFs or ocean buoy systems. They are also exchanged with other numerical forecasting centres so that values from different models may be compared. Every 6 months a report is provided to WMO for distribution to members. As such feedback often operates slowly and is not always effective, changes have been made within the numerical forecasting system at Bracknell in order that optimal use is made of the observations. A correction is applied to observations of pressure from those ships and buoys for which a constant and long-standing bias can be identified. Other ships, where the quality of the observations seems low and a correction cannot be made, are eliminated from use within the forecast system. The correction and rejection lists are updated regularly each month to allow for changes in quality.

Successful feedback of results is an essential part of all monitoring procedures. It is important that those making the observations are provided with convincing information on why the observations are considered to be of poor quality and what the characteristics of the errors seem to be. It is only in this way that observation errors can be corrected and the full potential of the global observing system can be realised.

Acknowledgements

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Wilkerson, J., 1986: Accuracy estimates of wind and wave observations from ships of opportunity in the WMO voluntary observing ship programme. European Space Agency Workshop on ERS-1 wind and wave calibration. Darmstadt, ESA, No. SP 262, 77–84.

Notes and news

Hydrological information

The International Association of Hydrological Sciences (IAHS) has submitted publicity material on the many titles published recently, e.g. *The physical basis of ice sheet modelling* and *Large scale effects of seasonal snow cover*.

Those interested in any hydrological subjects should apply to:

IAHS Press
Institute of Hydrology
Wallingford
Oxfordshire OX10 8BB
United Kingdom

or

Office of the Treasurer IAHS
2000 Florida Avenue NW
Washington, DC 20009
USA

Review

Pilots' weatherpack, by W.S. Pike, R. Reynolds and S.G. Cornford. 221 mm × 302 mm, pp. 24, *illus*. Reading, Royal Meteorological Society, 1991. About £3.50.

My impression of this weather pack is that it is a very clear and concise presentation bringing together examples of weather orientated aircraft accidents. The examples that have been studied emphasize how weather hazards are often encountered quite unexpectedly, irrespective of the time of year. With the upward trend of aircraft accidents, particularly amongst general aviation, this excellent information pack, when used for the training of pilots, serves a very useful purpose. It may also be useful in sixth-form Geography and Physics departments having a meteorology module in the syllabus.

The information emphasizes the important fact that a pilot must brief himself adequately to perform a safe flight and highlights the folly of flying on actual weather reports (METARs). Within the civil enclave, self briefing is the rule (AIC 30/1988) but a pilot can still talk to a forecaster at one of the three aviation centres (Bracknell, Manchester or Glasgow) for clarification purposes (AIC 30/1988) once the pilot has accessed some form of self-briefing data (AIRMET, F214/215 or WAFS charts).

Case 1: has been superbly illustrated with satellite pictures and highlights the impending dangers. Unfortunately FBUs (flight briefing units) do not have the benefit of satellite pictures. It should also be noted that the interpolation of satellite pictures, particularly IR (infrared) images, should be left to the 'professional' because wrong assumptions could be read into the analysis by the uneducated and inexperienced.

Case 2: highlights not only the foolishness of flying on actuals, and inadequate briefing, but also in not having sufficient training. A pilot may never know when he may be asked by ATC to descend, or climb, to a level which may be in cloud, to which an IFR (instrument flight rating) would be required.

Case 3: contains the message of avoiding flying near frontal zones because of the hazards.

Cases 4, 5 and 6: highlight the fact that air, in mass ascent, such as in a depression, or in well-developed areas of showers, or within organized bands of rain, can frequently result in the lowering of the main cloud base. This change in the cloud can invalidate a planned VFR flight.

Cases 7 and 8: highlight another important fact. When a cold easterly airstream becomes established, blowing out of Europe and across the United Kingdom, undercutting by the cold air forms some very strong inversions in the first few thousand feet. This has significant effects on air safety since engine performance is altered and also severe airframe ice may be experienced.

Although cases of airframe icing have been illustrated it must not be forgotten that carburettor icing is equally important on safe flying and so it is a pity that a case of carburettor icing has not been presented. However, the pack is well written and illustrated and is a good source of information to enlighten student pilots that the weather must not be taken for granted. Hopefully it will play its part in reducing aircraft accidents, and consequently save lives.

B.K. Lloyd

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Air traffic and the environment, edited by U. Schumann (Berlin, Heidelberg, New York, London, Paris, Tôkyo, Hong Kong, Springer-Verlag, 1990. DM 50.00) contains the proceedings of a German Aerospace Research Establishment (DLR) International Colloquium at Bonn in November 1990. The volume is the sixtieth in the series *Lecture notes in engineering* edited by C.A. Brebbia and S. Orszag. ISBN 3 540 53352 4.

Climate and development: climatic change and variability and the resulting social, economic and technological implications, edited by H.-J. Karpe, D. Otten and S.C. Trinidade (Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Barcelona, Springer-Verlag, 1990. DM 98.00) brings together interdisciplinary perceptions of the concerns about the subject which were voiced at the Hamburg Congress on Climate and Development. ISBN 3 540 51269 1.

Wave packets and their bifurcations in geophysical fluid dynamics, by H. Yang (Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Springer-Verlag, 1991. DM 78.00) is the first monograph on the subject. Some basic knowledge is included to make the book more readable to a wide range of researchers in allied areas. ISBN 0 387 97257 9, 3 540 97257 9.

Atmospheric particles and nuclei, by G. Götz, E. Mészáros and G. Vali (Budapest, Akadémiai Kiadó, 1991. £20.00) contains a presentation of the physical and chemical properties of aerosols. It is intended for students new to the subject, but also to be of use to research scientists. ISBN 963 05 5682 0.

Chemistry of atmospheres, second edition, by R.P. Wayne (Oxford, Clarendon Press, 1991. £45.00 (hardback), £19.50 (paperback)) lays the foundations for the study of the subject, on which rational decisions about environmental problems will need to be based. It is a 'necessary' second edition to incorporate recent developments. ISBN 019 855571 7, 019 855574 1.

Remote sensing in hydrology, by E.T. Engman and R.J. Gurney (London, Chapman and Hall, 1991.) is aimed at water resources scientists and managers. Each part of the hydrological cycle is detailed, and specific examples are used throughout. ISBN 0 412 24450 0.

The fragile environment, edited by L. Friday and R. Laskey (Cambridge University Press, 1991. £9.95, $15.95 (paperback)) explores the impact of the human species on its environment. The eight international contributors to this printing of the Darwin College Lectures address themselves to a broad readership. ISBN 0 521 42266 3, 0 521 36337 3.

Satellite photographs — 21 May 1991 at 0728 UTC

The main features of interest in the NOAA-10 AVHRR visible and infra-red (IR) images in Fig. 1 are the distinctive low- and high-level cloud patterns formed by horizontal and vertical wave motion, induced in the moist, stable, westerly airstream by the orography of Scotland and northern England. This airstream was on the northern flank of an anticyclone centred to the south-west of Ireland (Fig. 2).

Waves in the low- and middle-level cloud are most clearly seen on the visible image and have a wavelength of 5 km over north-east England (A), increasing to 10 km over central Scotland (B), and then to 15 km in much broader elements at (C) within the cloud band associated with the cold front. The westerly winds back a little just ahead of the front and this can be inferred by the different orientation of the waves at (C).
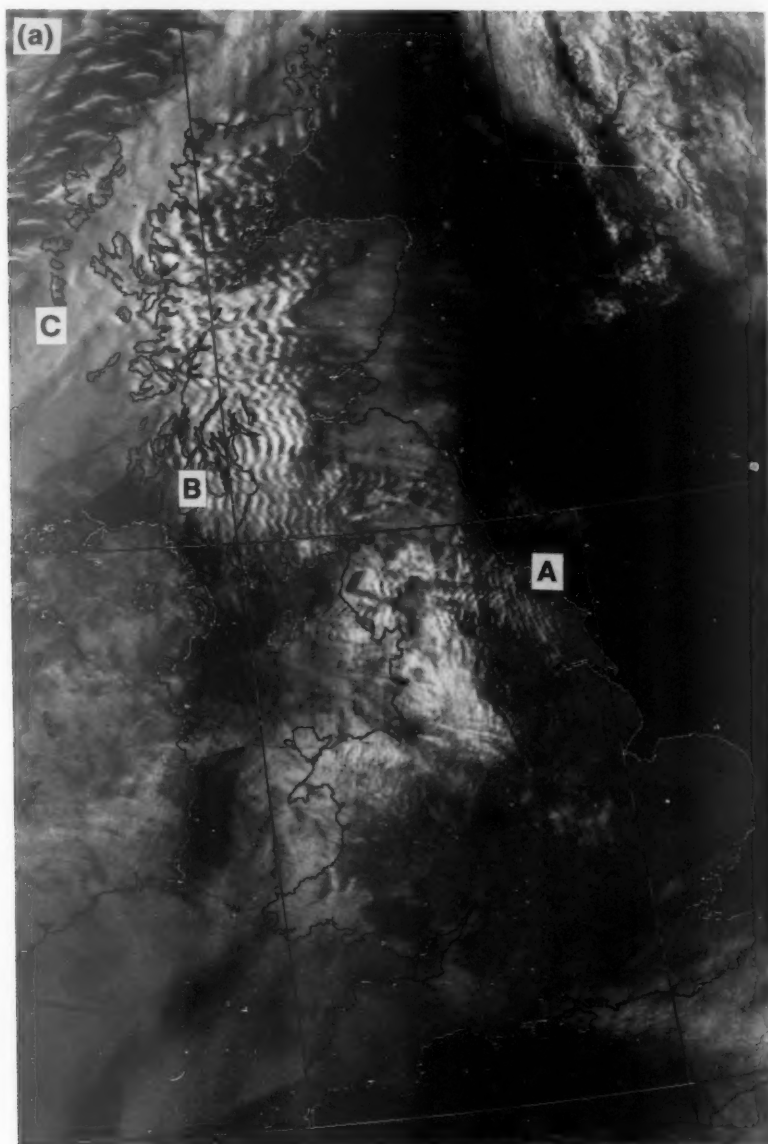
Photograph by courtesy of University of Dundee

Figure 1.   NOAA-10 AVHRR images at 0728 UTC 21 May 1991 (a) visible, and (b) infra-red. The labelling A–D is referenced in the text.

(b)

Figure 1. Continued.
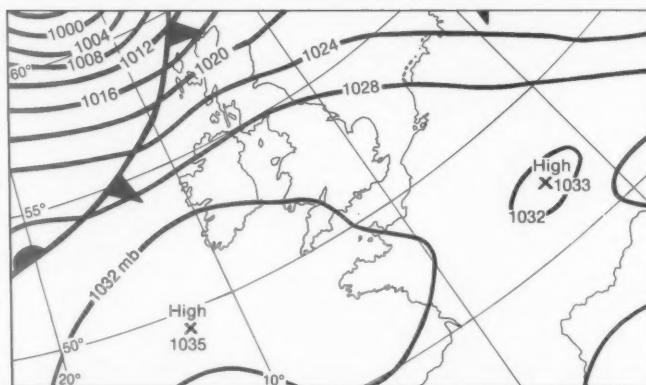
Figure 2. Surface analysis at 0600 UTC 21 May 1991.

On the IR image, these wave clouds are grey and therefore have relatively warm tops and the main feature is the area of orographic cirrus (D). The saw-toothed edge on the upwind side reflects the profile of the high ground. Comparison with the visible image shows the cloud to be relatively thin. Once formed in the vertically propagating waves, orographic cirrus can be very persistent and extend downstream in plumes for hundreds of kilometres. One factor that favours persistence is the fact that as air flows through upper-level waves, the level at which ice evaporates beyond the crest is lower than the condensation level upstream (see, for example, Scorer*). On static images it is often easy to confuse orographic and frontal cirrus, but movie-loops of images usually reveal clearly whether formation of the cloud is related to the high ground.

A.J. Waters and R. Bosworth

* Scorer, R.S.; *Cloud investigation by satellite*. Chichester, Ellis Horwood, 1986.

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe results of research in applied meteorology or the development of practical forecasting techniques.

Preparation and submission of articles

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately. Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

References should be made using the Harvard system (author/date) and full details should be given at the end of the text. If a document is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to, except by 'personal communication'.

Tables should be numbered consecutively using roman numerals and provided with headings.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and read. Notation should be kept as simple as possible. Guidance is given in BS 1991: Part 1: 1976, and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

Articles for publication and all other communications for the Editor should be addressed to: The Chief Executive, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

Illustrations

Diagrams must be drawn clearly, preferably in ink, and should not contain any unnecessary or irrelevant details. Explanatory text should not appear on the diagram itself but in the caption. Captions should be typed on a separate sheet of paper and should, as far as possible, explain the meanings of the diagrams without the reader having to refer to the text. The sequential numbering should correspond with the sequential referrals in the text.

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Contents